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AMERICAN PIONEERS IN METEOROLOGY [1]

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Pioneer weather observers.—The early colonists found the weather and climate of this continent a source of interest, and sometimes of surprise. The educated recorded the weather in their diaries and included it in their letters to the old country. One of these diarists, the Rev. John Campanius, of New Sweden, is acclaimed "first American weather observer" by Marcus Benjamin in the chapter on meteorology of the jubilee volume of the Smithsonian Institution, 1896. The diary kept by Campanius for the years 1644–45 at a fort near the present site of Wilmington, Del., was published by his grandson. Very few of such noninstrumental records have been published in this country, although, as Hellmann has shown, much can be gleaned from them.

Instruments for the quantitative measurement of the weather elements were rare in colonial times. The first were imported by Dr. John Lining, an eminent physician who migrated from Scotland to Charleston, S.C. in 1730. He imported a barometer, thermometers, hygrometer, and rain gage, and undertook systematic tridaily observations to ascertain the influence of atmospheric conditions on the human body, and upon the incidence of epidemic diseases. The history of these early observers has been written by Henry,[2] McAdie,[3] Varney,[4] and Abbe,[5] and their records have been collected and summarized by Schott.[6]

Founders of early weather services.—Hygienic climatology was the object of the first American weather service, that of the Army Medical Department, founded 1814, by an unobtrusive clause in the regulations issued by James Tilton, physician and Surgeon-General, Revolutionary War veteran, and member of the Continental Congress. The effect of this initiation of meteorological work was not important until the Army was expanded by John C. Calhoun, Secretary of War, to bring the Middle West and the Louisiana Purchase under the control of the Government. Then the meteorological service began a march with the frontier that ultimately carried it across the continent, and thus afforded us the first outlines of the climate of the country as a whole.

Another Revolutionary soldier whose hobby of weather observing led to the establishment of a weather service, was Simeon Dewitt, successively chief topographical engineer on the staff of General Washington, surveyor general of the State of New York, and vice chancellor of the University of the State of New York. In the latter capacity, he organized meteorological observations at the academies throughout the State, which continued from 1825 to 1863. This bureau performed noteworthy service in designing and testing instruments (the DeWitt rain gage was adopted by the Smithsonian meteorological system), and in training men like Joseph Henry, and James H. Coffin to do meteorological work.

Discovery of the law of storms and invention of the weather map.—One of those rare outbursts of intense activity in research and discovery that bring more progress in a decade than had occurred in the preceding millenium was going on in meteorology just a century ago.

One circumstance that stimulated progress here at that time was the beginning of the publication in this country of scientific journals. Aside from the Transactions of the American Philosophical Society (1771) the first of these was the American Journal of Science, founded by Benjamin Silliman of Yale in 1818, next the Journal of the Franklin Institute in 1826, and then the Proceedings of the American Philosophical Society in 1840.

The formative period of American meteorology has been well sketched by the eminent mathematician Maxime Bôcher, and I quote from his paper "The Meteorological Labors of Dove, Redfield, and Espy" (Am. Met'l Jol. 5, 1888, 1–13):

"The subjects which occupied the minds of meteorologists at the time to the exclusion of everything else was the theory of storms, both of wind and of rain, a region in which they found the paths as yet almost untrodden. The preceding meteorologists had done some valuable work, of which the most important was perhaps Hadley's (George Hadley, Concerning the Cause of the General Trade Winds, Phil. Trans. Vol. 39, pp. 58–63, 1735) partially correct explanation of the trade winds of the Torrid Zone [partially because he assumed the velocity of the air around the axis of the earth to remain constant with change of latitude, except as affected by friction with the surface of the earth, instead of inversely proportional to its distance from that axis, as it tends to be in accordance with the law of the conservation of areas. Also he neglected—it was not then known—the equal tendency of the air to deflect from its course whatever its horizontal direction.] They had not even a correct understanding of the motions of the atmosphere in a

[1] Presented at the meeting of the American Meteorological Society at the Century of Progress Exposition, Chicago, June 1933.

[2] Henry, A. J. Early individual observers in the United States. W.B. Bull. 11, 1893, 291–302.

[3] McAdie, A. Simultaneous meteorological observations in the United States during the 18th century. W.B. Bull. 11, 1893, 303–304.

[4] Varney, B. M. Early meteorology at Harvard College, Mo. Wea. Rev. vol. 36, 1908, 140–142, 286–290.

[5] Abbe, C. Chronological outline of the history of meteorology in the United States, Mo. Wea. Rev. vol. 37, 1909, 87–89.

[6] Schott, C. A. Tables and results of the precipitation in rain and snow in the United States and at some stations in the adjacent parts of North America and in Central and South America. Smithsonian Contr. to Know. 1st Ed. 1872, 2d ed. no. 353, 1881. Tables, distribution and variations of the atmospheric temperature in the United States and some adjacent parts of America. Smithsonian Contrib. to Know. no. 277, 1876.

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storm, much less could they explain them. In regard to rainstorms, however, there was one plausible theory, that of Hutton (James Hutton, 1726–97, Theory of Rain Edin. Trans. 1, 1788) who had shown that when two masses of air at different temperatures are mixed together, a portion of their moisture may be precipitated, so that the meeting of a warm and a cold wind would be the cause of a rainstorm. With the exception of this, we may fairly say that nothing was known about storms except that a northeast gale on our coast 'backs up' against the wind. (C.f. W. M. Davis, Was Lewis Evans or Benjamin Franklin the First to Recognize that Our Northeast Storms Come from the Southwest? Proc. Am. Phil. Soc. 45, 1906, 129–130.)

"In 1821, William C. Redfield, a mechanic (saddler) by trade with only a common-school education, had occasion to go from his home in Connecticut to the western part of Massachusetts, over the very region which a few months before had been swept by a violent September gale. The wind had left its record in the fallen trees, and as Redfield advanced and found the trees lying in the opposite direction to those near his home, it flashed upon him that the gale was a whirlwind on a large scale which advanced over the country from southwest to northeast, while at the same time it whirled around its axis in a direction opposite to that in which the hands of a watch move. This was Redfield's great discovery. However, he was a diffident young man, and it was only through a chance meeting with Prof. Olmsted of Yale, that he was induced to write an account of his theory of storms. It was not until the year 1831 that he was able to publish his first meteorological paper, Remarks on the Prevailing Storms of the Atlantic Coast and of the Northeastern States (Am.J.Sci. 20, 1831, 1–36). This article is devoted in great part to the storm of 10 years before and contains a considerable number of independent observations extending over all our Atlantic coast. He thus puts his whirlwind theory on a firm foundation and also makes his second great discovery, that these storms move, roughly, in a parabolic path. These two important principles are here established independent of any theory."

"However decisive the array of facts brought forth in these early papers may appear to us, it seems to have been very far from carrying conviction to the minds of several contemporary meteorologists. Of these the most notable was Espy (James Pollard Espy, 1785–1860) who from this time forth appears as the persistent opponent of Redfield both as to facts and theory." Neither Redfield nor Espy was aware of "Hadley's principle" of the deflective effect of the earth's rotation. Espy, who was well grounded in the physics of his day, could not admit the rotation observed by Redfield because he knew of no force capable of producing it, but insisted that the wind always blows inward from the edge of the storm to a central point or line. Espy's contributions to meteorology were chiefly the theory of convection and the thermodynamics of moist air in vertical motion. As early as 1828, Espy had seen the importance of water vapor, but it was not until 1836 that he first made known his theory of storms in some papers published in the Journal of the Franklin Institute. As there stated his theory is as follows: "When a portion of transparent vapor in the air is condensed into cloud or water, the latent caloric given out expands it six times as much as it is contracted by the condensation of vapor into water" so that "the moment a portion of vapor begins to condense into cloud, the air in which it is contained begins to expand, and consequently if an equilibrium existed before, it is now destroyed and the cloud will continue to ascend so long as its temperature is greater than that of the surrounding air." Espy argued that "as this air rises other air will rush in from all sides to take its place, and this in turn will rise, thus forming what Espy calls a vortex, near whose center there will usually be rain, and toward whose center the wind will blow. Moreover Espy's theory explained not only a windstorm with a rainy center, but also a hailstorm when the raindrops carried upward until congealed are thrown out at one side, and waterspouts and landspouts, which are merely small vortices of unusual violence which reach down to the ground with their accompanying cloud, and lastly but most important of all, the diminution of barometric pressure at the center of storms, for we have here a column of relatively warm and consequently light air."

Redfield, as early as 1834, expressed the opinion that the typhoons of the China Sea were similar to West Indian hurricanes; that the storms of the Southern Hemisphere would be found to rotate in the opposite direction to those of the Northern Hemisphere, and to follow paths recurving in the opposite direction from the Equator; all of which were found to be true a few years later when the facts were investigated.

Redfield was fortunate in his proselytes. The first of these was Lt. Col. William Reid (1791–1858) who had won reputation in Spain under Wellington. Reid came out to Barbadoes as governor in 1831 just after that island had been devastated by a hurricane. Redfield's first paper came into his hands at that time, with the result that he entered into correspondence with Redfield (three volumes of which are said by Reid's biographer to be in Yale University), and devoted many years to the study of tropical storms, and the formulation of the "law of storms" to enable seamen to escape destruction. After returning to England, Reid had the East India Co. assign to Captain H. Piddington, curator of a museum in Calcutta (1797–1858) the duty of studying the storms of the Indian seas. Piddington coined the word "cyclone" and in 1848 published that popular treatise on maritime meteorology, "The sailor's hornbook of storms in all parts of the world." This torch of research was handed on to the island of Mauritius, where Thom and Meldrum worked out the peculiarities of the cyclones of the South Indian Ocean.

Espy also built up a more local circle of collaborators. The American Philosophical Society and the Franklin Institute supported a joint committee of influential men, of which Espy, and later Dr. Dunglison, was chairman. This committee in 1834 organized a net of observing stations covering the Atlantic and Gulf States, and the Ohio Valley from Canada to Louisiana, and began collecting data and mapping storms. The committee obtained a grant of $4,000 from the Pennsylvania legislature in 1837 to be expended in equipping one observer in each county of the State with a barometer, two ordinary thermometers and a self-registering theremometer, and a rain-gage.

Espy went to Europe in 1840 to explain his theory of storms. His address before the British association was discussed by Sir John Herschel and Sir David Brewster, and published in the report of the association for 1840. In France he met a most enthusiastic reception. Introducing him to the Academy of Science, Arago placed Espy on a par with Newton. His "Brief outline of the theory of storms" was commended by the academy and published in the Comptes Rendus, 1841, p. 454. Coincident with his return to Boston, Espy's "Philosophy of Storms" came from the press. This is an elaborate presentation of his theories, supported by numerous instances, with applications to the explanation of many atmospheric phenomena. In later years, it has been undeservedly neglected, with the result that others have received credit for discoveries that had already been made by Espy, e.g. the Koeppen-Espy theory of the daily march of wind velocity (cf. "Philosophy of Storms," p. xiv).

Elias Loomis (1811–89) followed with great interest the debate between Redfield and Espy, which was at its height in the years between his graduation from Yale in 1830 and entrance on his professorship of mathematics and physics at Western Reserve College near Cleveland, Ohio, in 1836. He was allowed to spend the first year of this professorship, 1836–37, in Paris where he attended the lectures of Biot, Poisson, Arago, Dulong, Pouillet, and others. After his return to the States, in addition to his teaching, he carried on original research in terrestrial magnetism, the aurora borealis, and meteorology, and set up and made important observations with astronomical, magnetic, and meteorological instruments, which he had bought in Europe. In studying all the circumstances of a tornado, Loomis was led to the discussion of two storms of great extent that occurred in 1836 and 1842, in papers read before the American Philosophical Society at Philadelphia. The second of these papers created a great sensation, because it published the first synoptic weather map of isobars and isotherms. A sketch of the vertical movements at the squall front, that appears in this paper, anticipates modern views with remarkable accuracy. Loomis in 1868 published his well-known textbook on meteorology, and after the beginning of the Signal Corps meteorological work, Loomis presented 18 "Contributions to meteorology" to as many successive semiannual meetings of the National Academy of Sciences, in which were brought together and discussed facts about the cyclones and anticyclones of the entire globe, and matters regarding the distribution of rain.

Paralleling, and in some cases antedating, the development of meteorological theory in America, attacks on the same problems were going on in other parts of the world. For example, Capper, in 1801, inferred that the tropical storms of the Coromandel coast of India were "whirlwinds whose diameter cannot be more than 120 miles" ("Observations on winds and monsoons") Romme ("Tableaux des vents, des marées et des courans"), 1806, describes a typhoon of the Gulf of Tonkin as a "tourbillon", and H. W. Brandes (1777–1834), then professor of mathematics at Breslau, later of physics at Leipzig, began in 1817 a study of the weather of each day of the year 1783, in which he prepared 365 charts with lines of equal deviation of the pressure from the normal, and arrows to show the direction of the wind. Unfortunately none of these charts were published, but Hildebrandsson has reconstructed one of them from the same data. H. W. Dove (1803–79), although 20 years younger than Redfield or Espy, began to write before either of them and continued until his death in 1879. His doctor's thesis "Ueber barometrische Minima" (Pogg. Ann. 13, 1828, 596), announces his theory of storms, which he connects with Hadley's theory of the trade winds by supposing that in the temperate and polar zones, polar and equatorial winds are placed side by side, instead of over one another as in the torrid zone. This part of Dove's theory, which Bôcher, 45 years ago, spoke of as exploded, is identical with the scheme of atmospheric circulation shown in the frontispiece to Hobb's "Glacial Anticyclones" 1926, and is not very different from the modern polar-front theory. There was active interchange of views between Dove, Redfield and Espy, without unseemly discussion as to who should have the honor of priority.

The work of these men brought into being the science of meteorology, as yet wholly qualitative, but capable of supporting a commercially valuable art, that of predicting storms.

The founding of national weather-forecasting services.—Of all these early meteorologists, Espy was most keenly alive to the possibility of practical applications. Immediately after his return from France in 1841, he proceeded to Washington with a plan for the establishment of a national weather service. The records of Congress show that he enlisted the support of some of the ablest statemen of that day, but the public was so tax-conscious that the most that was dared was to provide an irregular compensation for Espy by adding a last-moment amendment to one appropriation bill or another at session after session until the year before his death in 1860.

John Quincy Adams, a Member of the House (after his term as President of the United States) and well known for his interest in science—he had tried to secure an appropriation for the five meteorological and magnetic observatories asked by Sabine in 1839 in cooperation with the Antarctic Expedition of James Clark Ross, and was chairman of the Smithson bequest committee—says of Espy, (Memoirs, vol. 11 p. 52):

(January 6, 1842) "Mr. Espy, the storm breeder, who had notified me at Boston that he would be here at the beginning of the year, punctual to his time, appeared yesterday at the House, and requested me to fix a time for an interview. I appointed him 9 o'clock this morning. He left with me a paper exposing his three wishes of appropriations by Congress for his benefit—about as rational as those of Hans Carvel and his wife. The man is methodically monomaniac, and the dimensions of his organ of self-esteem have been swollen to the size of a goiter by a report of a committee of the National Institute of France endorsing all of his crackbrained discoveries in meteorology. I told him with all possible civility that it would be of no use to memorialize the House of Representatives in behalf of his three wishes. He said that he had thought of addressing the Senate, and asked if they should pass a bill in his favor whether I would support it in the House. I said that if the Senate should pass such a bill I would do all that I could for him in the House."

(January 19, 1842) "Meeting of the select Committee of the Smithsonian Bequest. Habersham presented a letter from James P. Espy, proposing that a portion of the fund should be appropriated for simultaneous meteorological observations all over the Union, with him for central national meteorologist stationed at Washington with a comfortable salary."

Although frustrated in his plan for a national weather service, Espy had positions in the Surgeon General's office and in the Navy Department, where he had the use of reports from military posts and from ships, in addition to the corps of volunteer civilian observers that he had organized at Philadelphia in 1834. From these he prepared four reports on meteorology, summarizing the laws of storms and illustrating by maps and graphs the progress of storms across the country. Adams refers to this work (vol. 11, p. 506, February 8, 1844) "Mr. Espy, the storm breeder, came with a complaint that the Committee on Ways and Means were about to retrench the appropriation for some small interloping office under the War Department with which he has been allowed for the last 2 years to pursue the study of storms. He said that he had contemporaneous observations made at a hundred and fifty military stations, the results of which he had reported to the Secretary of War, and his report had been communicated with that of the Secretary, accompanying the President's message; and he showed me 90 engraved maps on which were marked the direction of all of the storms at the several stations of observation, all confirmative of his theory." Matthew Fontaine Maury (1806–73), assigned in charge of the Depot of Charts, U.S.N., on July 1, 1842, reverted to the subject of ocean currents, in which Benjamin Franklin had achieved both scientific and practical results. Maury's work in collecting half a million observations of winds and currents from the logs of ships and summarizing them for the benefit of mariners fell, opportunely, in the clipper-ship period, and brought him numerous medals, orders of nobility, and a $5,000 service of silver. His Physical Georgraphy of the Sea went through 30 editions in half a dozen languages. He brought about the international conference on maritime meteorology at Brussels in 1853.

Means of rapid communication, lacking when Espy appeared before Congress in 1842, were provided by Morse and Vail in 1844. By 1846, the telegraph net had spread so far that Redfield pointed out that it was now practicable to give warning by telegraph of the approach of West Indian hurricanes. (Am.J.Sci. 2d ser., vol. 2., 1846, p. 334.)

Joseph Henry, who had been in close touch with the meteorological work at Philadelphia from his nearby post at Princeton, became secretary and director of the Smithsonian Institution when it was founded in 1846. An important place in his program was found for meteorological work, and he enlisted the aid of Espy and Loomis in persuading the regents to his point of view. A corps of 150 observers, incorporating Espy's correspondents was equipped and began observing in 1849. Eventually these were increased to over 500. Telegraphic observations were talked of from the first, but were not actually collected until 1857. Experiments were then made in weather forecasting (Henry, J., "Application of telegraph to prediction of changes of weather" Proc. Am. Ac. of Arts and Sci. 4, 1857–60, 271–275). Meantime, in 1855, Leverrier took advantage of the need demonstrated by the loss of the supply fleet of the Allies in the Crimean War in a great storm in the Black Sea, to procure from the Emperor of the French means sufficient for a magnificent weather service that began operations on February 17, 1855, extended over Europe in 1857, and published daily weather charts, beginning September 10, 1863.

Henry renewed his demonstrations of weather telegraphy in 1861 and 1862, but in spite of the great need for weather information in the movement of armies and planning of battles, was not able to get support for the service that he proposed. When Leverrier's maps began to arrive, and news came of the creation of weather forecasting services in every European country, including Turkey, Henry redoubled the fervor of his appeals, but neither the six influential members of Congress on the board of regents of the Smithsonian Institution, nor any other legislator would place his recommendations before Congress.

The present United States Weather Bureau was created by legislation put through Congress by Gen. Halbert E. Paine, Representative from the Milwaukee district, and signed by the President on February 9, 1870, Congressional documents show that Paine was stimulated to this action by a petition written by Increase A. Lapham, a naturalist living in Milwaukee, Wis. This petition recited statistics of marine disasters on the Great Lakes, and pointed to the feasibility of storm warnings on the basis of Espy's findings, and the experience of Leverrier in France. Paine was peculiarly susceptible to this appeal inasmuch as he had been one of Loomis's students at Western Reserve College 25 years before. Lapham had been observer for both Espy and Henry, and was stirred to action at this time by the success of Cleveland Abbe, who demonstrated weather mapping at Cincinnati with the aid of local newspapers and the Western Union Telegraph Co., in a trial beginning September 1, 1869.

The work of building up the new meteorological organization fell upon Chief Signal Officer Albert J. Myer, formerly an Army surgeon, who had invented the now-familiar wigwag signals with flags and torches to replace couriers as a means of military communication. Myer undertook the new work with unbounded energy and ambition. He trained observers, arranged telegraph circuits, equipped stations, and began operations within 9 months after the enactment of the Paine bill. The success of the work was immediate. Within 2 years the demands of the public had added "prediction of the weather for the benefit of commerce and agriculture", the gaging of rivers and the forecasting of floods. The collection of marine intelligence, which had fallen into abeyance after Maury threw in his lot with the Confederacy, was revived by General Myer. The financial panic of 1873 tied up the funds of the Smithsonian Institution, then in a private bank, and compelled Henry to offer the Smithsonian meteorological system to Myer. The transfer occurred in 1874, and included the meteorological work of the Medical Department of the Army. In addition to these routine duties, Myer, as member of the International Congress of Meteorology at Vienna in 1873, persuaded the representatives of other nations to join in international simultaneous observations, the mapping and publication of which fell to the United States. Abbe calls this "the finest piece of international cooperation in scientific work that the world has ever seen."

In June 1871 Myer took over the mountain observatory that had been established on Mount Washington by Hitchcock, of the New Hampshire Geological Survey, 6 months earlier. In 1873 observatories were set up on Mount Mitchell, N.C., and Pikes Peak, Colo. The first and last of these mountain observatories were continued for many years, and contributed valuable information about the meteorology of the upper air. Myer also cooperated with several polar explorers by detailing trained meteorologists to accompany them.

Pioneers in dynamical meteorology.—No mathematics more advanced than arithmetic was invoked in the theoretical meteorology of Halley, Hadley, Dove, Redfield, Espy, and Loomis, nor in the applied meteorology of Leverrier and Myer. This is the more remarkable inasmuch as the science of mechanics, founded in the sixteenth and seventeenth centuries by Galileo (1546–1642), Kepler (1571–1630), and Newton (1642–1727), had been brought to perfection as a mathematical science by Euler (1707–83), d'Alembert (1717–83), Lagrange (1736–1813), and Laplace (1749–1827) in the eighteenth century.

The relation of wind to pressure, and the deflective effect of the earth's rotation were expressed in their final analytical form as early as 1835 by G. G. Coriolis (1792–1843) director of studies in the École Polytechnique, one of the two French government schools (the other being the École Normale Supérieure) which lead the world in mathematical physics. (Coriolis, "Sur la manière d'ètablir les différens principes de mécanique pour des systèmes de corps en les considérant comme des assemblages de molécules" Paris, J. École Poly., 15, 1835, 93–125 and "Sur les équations du mouvement relatif des systèmes de corps," same p. 142–154) Poisson applied the theory of the deflective effect of the earth's rotation to the motion of projectiles in the very year (1837) that Loomis attended his lectures, that is to say, at the moment when this principle if known, would have resolved the difference between Redfield and Espy and anticipated Ferrel by 20 years.

The circulation of the atmosphere as a whole, first considered by Halley in 1686, and more adequately by Hadley in 1735, lay untouched until Maury's "Wind and current charts" brought him face to face with the same problem. His model of the winds aloft, although supported by authorities ranging from the Hebrew prophets to Faraday's recent discovery of the paramagnetism of oxygen, was unsatisfactory to a Nashville, Tenn. high-school principal, whose hobby was celestial mechanics and hydrodynamics. This was William Ferrel (1817–91) whose first paper on the subject, a nonmathematical outline of his theory, appeared in the Nashville Journal of Medicine and Surgery, October-November 1856. In the following year, Ferrel joined the staff of the Nautical Alamanac Office, at Cambridge, Mass., and there worked up his ideas and reasoning into a mathematical paper which was published in Runkle's Mathematical Monthly, vols. 1 and 2, 1858 and 1859, and in simplified form in the American Journal of Science, 1860.

Ferrel's model of the general circulation of the atmosphere was necessarily based on few observations in the Arctic and none in the Antarctic, and was subsequently changed by himself in 1860 and 1889. The 1889 model differed inappreciably from the circulation proposed, without mathematical analysis, by James Thomson, brother of Lord Kelvin, before the British association in 1857. However, Ferrel's earlier intuition proves to be more in accord with the working picture formed by Hildebrandsson and de Bort from more complete collections of data. (Hobbs, Glacial Anticyclones, 1926, p. 19.)

Ferrel's great contribution to meteorology was the discovery and mathematical formulation of the laws of motion of the atmosphere on a rotating globe. Following his pioneer effort, Sprung, Guldberg and Mohn, Helmholtz, Margules, Siemens, Oberbeck, and Rayleigh have worked to improve and extend the subject. Ferrel's mathematical style has been criticised as lacking finish, but Marcel Brillouin, of the École Normale Supérieure, who reproduced Ferrel's papers in his "Mémoires originaux sur la circulation générale de l'atmosphère" says in his introduction, p. vii, "one cannot sufficiently admire this collection of Ferrel's memoirs; in the rigor of reasoning as well as in the subtlety of ideas, the student of Nashville is a worthy predecessor of von Helmholtz."

Sir Napier Shaw points out that meteorological theory has been invariably hampered by want of facts. All the work on dynamical meteorology before Helmholtz he regards as "interesting speculations about a planet which does not represent the earth as we know it, nor can the application to the real earth be developed by any slight modification of the hypothesis." Helmholtz, however, "opens out a new province by using his reasoning to develop certain processes which are operative in any part of the atmosphere in accordance with the laws of dynamics and reaches conclusions which one may expect to find illustrated wherever the atmosphere admits the prescribed assumptions." The chief problem of meteorology today is the discovery of the facts, and the adaptation of theory to them in detail. Shaw names Buys Ballot, Buchan, de Tastes, and Duclaux, Hildebrandsson, Teisserenc de Bort, Hann, and Koeppen, as representatives of this inductive school of theoretical meteorologists. To these we may add Shaw himself, and the Bjerkneses, father and son. Among Americans, Frank H. Bigelow's prodigious labors on the "International Cloud Observations", "The Barometry Report", and a long series of papers on the general circulation of the atmosphere in the Monthly Weather Review, 1902–6, fall into this class.

Among signs that meteorology is approaching the standard set by astronomy, the "precision of which in predicting the positions of the heavenly bodies is the admiration and the envy of all other sciences" (Shaw, Man. of Mety., pt. 1, p. 316) are the graphical calculus of atmospheric motions of V. Bjerknes (Dynamic Meteorology and Hydrography, 1911) and the most explicit example of quantitative forecasting, of Richardson (Weather Prediction by Numerical Process, Cambridge, England, 1922). The latter scheme is designed to forecast the weather of the whole world, and the author estimates the number of computers required to "race the weather" at the staggering number of 64,000. It is therefore obvious that further pioneering as well as improvement in economic and political conditions is necessary before the qualitative meteorology handed down to us by Redfield, Espy, and Loomis can be superseded by the quantitative meteorology of Helmholtz, Bjerknes, and Richardson.